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The Study of Geometric Parameters of Cutting Tool of a Rail-Milling Train

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ABSTRACT

The article presents the methods of study of geometric parameters of a working tool of a rail-milling train after revealing after the process of controlled operation of milling the polygon-shaped transverse profile of R65 rails not meeting the requirements of the standard. Those methods were tested in the case of rail-milling train of RFP-01 model. To eliminate the causes of formation of a poor-quality transverse profile, the specialists of JSC VNIKTI conducted a series of studies to establish the actual profile and incline of a working tool of milling wheels which are plate-holders with carbide plates. A plate-holder from each milling wheel was randomly selected. The geometric parameters of plate-holders were measured with a coordinate measuring machine. As a result of measurements, clouds of points of working surfaces of plate-holders were obtained. To compress and recognize images, a singular n×3 matrix decomposition was used, where n is the number of rows equal to the number of points in the cloud, the columns are the coordinates X, Y, Z. The next step was to split the point cloud into triangles using the Delaunay triangulation algorithm.

Using the above methods, plate-holders' cutting lines were obtained that form the actually shaped rail profile. The cutting lines were aligned relative to the vertical axis with the R65 rail profile as per the condition of achieving the minimum root-mean-square deviation. As a result, the reasons for poor-quality shape of R65 rail profile after milling were established, and recommendations were formulated for their elimination.

Keywords: railways, coordinate measuring machine, milling wheel plate-holders, point cloud, cutting surface, Delaunay algorithm, singular decomposition of the point cloud of cutting surface of plate-holders.

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Rail milling: state-of-the-art

Rail milling is used to restore the shape of the rail head to suit the target profile (hereinafter the case of a new R65 rail is considered), to remove long and short wave-like irregularities, and to remove the defective metal layer from working surfaces of rail heads on the track [1–3].

In case of Russia requirements, the criterion for choosing the type of technology for surface treatment of rails is the depth of contact fatigue defects: grinding is used with a depth of defects less than 0,8 mm, and milling with a depth of 0,8 to 3,5 mm [4].

Track machines of mechanical treatment of rails should ensure compliance with the set standards of surface treatment, in the considered case they should comply with standards with regard to R65 rails. Obtaining of required parameters when new types of rail track machines, e.g. rail-milling trains, are manufactured, is associated with debugging. The JSC VNIKTI has developed the set of methods to eliminate the defaults revealed during testing. The *objective* of the article is to describe the methods of the study of geometric parameters of a working tool of rail-milling train. The study of RFP-01 rail-milling train was used as the case.

Results.
Case conditions

To implement the technology of milling of rails, JSC Kaluga Remputmash [Track Repair Machines] Plant together with the Austrian company MFL manufactured the RFP-1 rail-milling train, which simultaneously processes the rolling surface of both rails to a depth of up to 3,5 mm in only a single pass [5]. Instructions were developed for milling of rails along the route followed by the description of an experimental technological process «Operations using the RFP-1 rail-milling train» [6; 7].

When testing the RFP-1 rail-milling train on both the right and left rails, a broken profile was formed with a lowering of the rolling surface towards the outer side of rails. This pattern was observed on all profiles. An acute angle was formed in the mating zone of the treated and untreated surfaces [8; 9]. A typical broken profile of the rail head after milling is shown in Pic. 1. The red color (the corresponding line is also indicated by the upper arrow in the left and right parts of the picture) in the picture indicates the new R65 rail in accordance with GOST [State standard] 51685-2013, the green color (or lower arrow) shows the rail profile after milling.

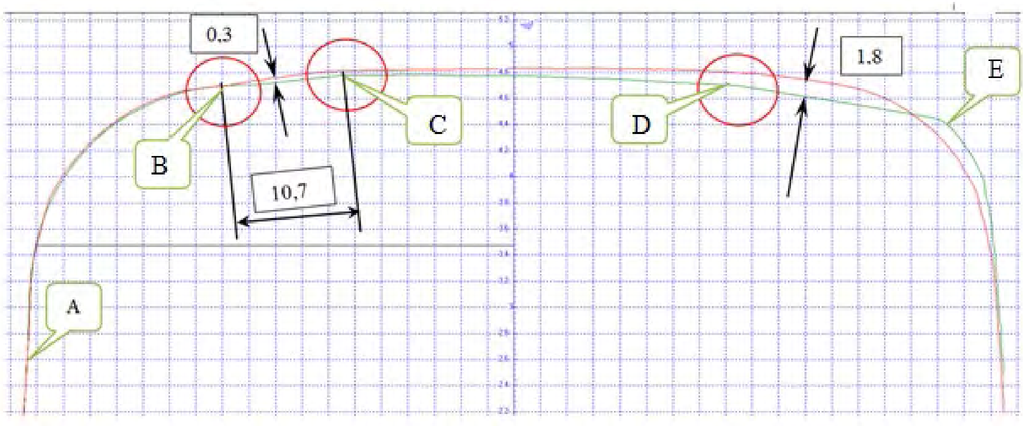
Analysis of the transverse profile of the rail shaped during milling showed the need for conditionally dividing the transverse profile into several zones. The boundaries of zones are fixed by the letters of the alphabet.

It has been established that:

• profiles coincide completely in the zone on the working coving of the side face (in the area from A to B);

• on the inner side face of the profile (working face) following the coving (from B to C) instead of the mating radius of 80 mm a straight section of 10,7 mm wide is formed, forming a longitudinal strip, with a depth in the middle part of up to 0,5 mm;

• on the section from C to D, which is determined by a radius of 500 mm of the rail



Pic. 1. Transverse profiles of a new R65 rail and a rail milled simultaneously by two SF-1 and SF-2 sections of the rail-milling train; incline is 1:20 [8; 9].

Pic. 2. Fusion-6 coordinate measuring machine manufactured by FARO. [Electronic resource]: http://www.metrologi.ru/img/flash/browyri/trexmer_kontr/kim_faro/fusion_arm5.pdf. Last accessed 20.10.2019.

head, the milled profile has an angular shift clockwise with respect to the original profile, which is possible when the axes of symmetry of the rail and the milling wheel diverge;

• on the outer surface of the rail head (non-working face) instead of a smooth surface of a symmetrical working face there is a surface with a fracture of the profile at points D and E. In D–E section, an inclined platform is formed with an understatement from a given profile up to 2 mm.

Thus, the transverse profile formed during milling by RFP-1 rail-milling train coincides with the given profile R65 only in the zone of the working coving, in other sites it does not correspond to the required shape.

Algorithm and methods for determining geometric parameters of a cutting tool of milling wheels

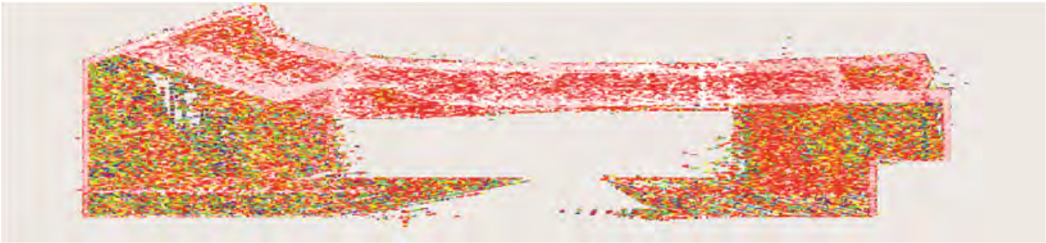
To establish the reasons for formation of the profile with a deviation from the new R65 rail profile, it became necessary to determine geometric parameters of cutting surfaces of plate-holders of milling wheels of the RFP-1 rail-milling train to assess the degree of profile deviation. The study used as objects four plate-holders, dismantled from four milling cutters: two from the milling section No. 1 and two from the milling section No. 2 [10]. The geometric parameters of plate-holders were determined using a coordinate measuring machine (CMM), in our case we used CMM FARO Fusion-6 (Pic. 2)[1].

The design of CMM FARO is similar to the structure of a human hand. It has a shoulder, ulnar and carpal joints. There is a mounting plate on the shoulder joint, with which the machine is mounted on a flat surface. A measuring probe is mounted on the wrist joint.

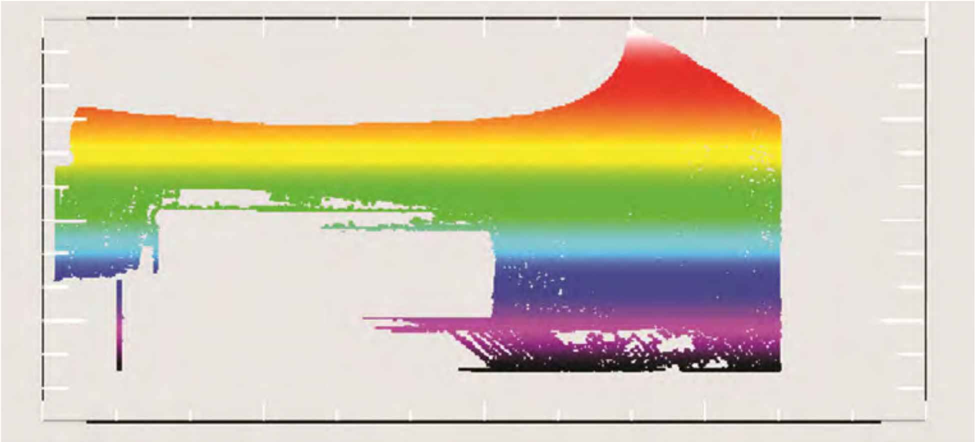
Each joint has angular displacement sensors. In real time, CMM calculates rotation angles of each of 12 rotation angle sensors and coordinates of the measuring probe in space.

CMM performs measurements in the working area of 1800 mm with a repeatability

[1] FARO Quantum Arm. https://www.vivtech.ru/production/kim_faro/faro_arm.



Pic. 3. The cloud of points of plate-holders in isometric view of the side surface of the plate-holder and the cutting surface [11].



Pic. 4. The cutting line of the plate in YZ plane built on the point cloud data [11].

of measuring the point of 0,036 mm with an accuracy of linear measurements of ±0,051 mm.

The complete measurement of four plate-holders of milling wheels of the rail-milling train RFP-01 was carried out.

As a result of measurements, a point cloud was obtained for each plate-holder. The results of measurements of the cloud of points of the working surface of the plate-holder are shown in Pic. 3.

From the common point cloud obtained as a result of measurements, point clouds for each of the carbide plates are selected. For each point cloud, using matrix transformations (singular expansion) [12] and using the Delaunay algorithm [13; 14] (dividing a point cloud into triangles), points lying in the horizontal and vertical planes of carbide plates were determined.

Based on the selected points, a formula of the plane of the form was derived:

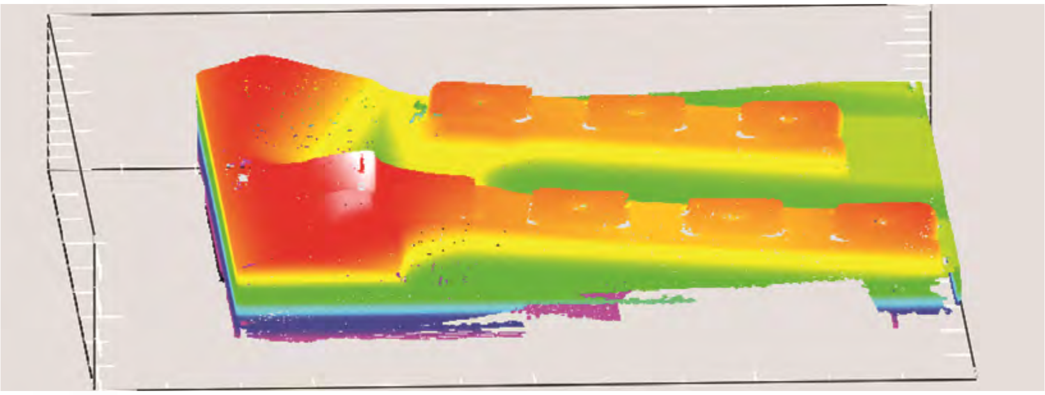
$$x \cdot \cos a + y \cdot \cos b + z \cdot \cos c - p = 0,$$

where a, b, c are angles of the normal vector of the plane to the axes X, Y, Z.

The shape of the cutting edge line of the carbide plate was defined as the intersection of the front vertical and horizontal planes. Around the line obtained, real points from the original point cloud are selected. By combining the cutting edges of all the plates on the plate-holder, a plate-holder cutting line is obtained that forms the actual shaped rail profile (plate-holder cutting profile). The results of building the cutting line of the plate-holder are shown in Pic. 4.

Using the spatial coordinates of the point cloud, an isometric image of plate-holders is built. The image of carbide plates on the working surface of the plate-holder built from a point cloud is shown in isometry in Pic. 5.

The cutting line of the plate-holder, forming the actual rail profile after processing, and the rail profile R65 according to GOST R51685-2013 [15] were aligned relative to the vertical axis of the rail according to the condition of maximum coincidence of the contours, that is, until the minimum root-mean-square deviation (RMS) is achieved. By superimposing the cutting line of the plate-holder, forming the actual profile of the rail R65 after processing, and the profile of



Pic. 5. An image of a plate-holder with carbide plates in isometry in XYZ coordinates built on point cloud data [11].

Table 1

The results of calculations of incline on the cutting surface of cutters [12]

No.	Pate-holder number	Rotation angle, °	Incline
1	383_84	1,5	1:38
2	383_54	1,3	1:44
3	384_15	1,7	1:34
4	384_74	1,8	1:32

the rail R65, the position of the vertical axis *Z* of the plate-holder is obtained.

Based on the results of applying the profiles of the cutting lines of the plate-holder and the profile of the rail R65, the angle between the axis of symmetry of the transverse profile of the rail and the vertical axis *Z* of the cutting line of the plate-holder, which forms the actual profile of the rail after processing, was determined based on which the actual incline was determined.

The cutting lines constructed in accordance with the procedure for processing the measurement results were combined with the new R65 rail profile until the minimum RMS deviation between the superimposed profiles was achieved. The results of the combination and the calculation of incline of the cutting surface of the plate-holder is presented in Table 1.

Thus, the magnitude of the incline calculated from the measurements on the selected plate-holders, one from each cutter, varied from 1:32 to 1:44. The obtained values of the incline are close to the normative structure of the European rail gauge (1:40) and do not comply with the requirements [16], which determine the value of the incline 1:20 for Russian railways.

The measurement results of the geometry of the cutting tool

The results of combining the rolling surface of R65 rail and the cutting line obtained by measurements that are approximated by the «highest» line of ledges of irregularities, that is, R65 profile and the profile deployed to the actual cutting surface for all four plate-holders showed that:

• cutting profile of the plate-holder No. 1 has a surface close to the R65 profile;

• cutting profile of the plate-holder No. 2 has a surface that differs from R65 profile more significantly, taking into account wear of the cutting faces of the plates;

• cutting profile of the plate-holder No. 3 has a surface that is even more different from the R65 profile, taking into account more severe wear of the cutting faces of carbide plates;

• cutting profile of the plate-holder No. 4 has local horizontal sections with large protrusions resulting from improper adjustment of plates 1 and 3 of row No. 1 and plates 2 and 3 of row No. 2 of the plate-holder.

Conclusions

1. To establish the causes of formation of the R65 rail profile after milling by RFP-1

train, measurements were made of the geometric parameters of the cutting surfaces of the milling wheel of plate-holders using high-precision coordinate measuring machine.

2. A technique has been developed for determining the geometric parameters of the cutting tool of milling wheels with conversion of a point cloud by the method of singular decomposition and for construction of 3D models of plate-holders using Delaunay algorithms.

3. As a result of studies of geometric parameters of the cutting line of the plate-holders, the causes of the repeated defects of the rail profile shaped after milling are established:

• discrepancy between the value of actual incline of the plate-holders and the standard rail incline's nominal value established on the Russian railways;

• low-quality adjustment of the cutting faces of plates on the measuring table;

• lack of radial runout test.

Values of the actual incline of the plate-holders are close to the regulated status of the European rail track (1:40), but not to the Russian one (1:20).

The actual incline on randomly selected plate-holders on four milling wheels has a scatter from 1:32 to 1:44.

The relevant recommendations were addressed to rail-milling train manufacturers.

The set of methods to study geometric parameters of the cutting tool described in the article seems to be quite universal to be used under the conditions prevailing at railways of different countries, once its target parameters are adapted to relevant standards.

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